Enhanced Coal Bed Methane (CBM) Recovery and CO_2 Sequestration in an Unmineable Coal Seam

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ABSTRACT

CONSOL Energy Inc. (CONSOL), with funding from DOE, has begun field construction on a seven-year project to evaluate both CBM recovery and CO_2 adsorption capacity of an unmineable coal seam. The project will demonstrate the application of a series of wells, drilled from the surface and extending up to 3000 feet horizontally, to drain CBM from an unmineable coal seam in the Appalachian basin. In time, some of the wells will be used for CO_2 injection/sequestration, which will further enhance CBM recovery. This approach offers CBM recovery and CO_2 sequestration over a large areal extent of the reserve from one surface location.

INTRODUCTION

The availability of clean, affordable energy is essential for the prosperity and security of the United States and the world in the 21st century. Emissions of carbon dioxide (CO_2) into the atmosphere are an inherent part of electricity generation, transportation, and industrial processes that rely on fossil fuels. These energy-related activities are responsible for roughly 85 percent of the U.S. greenhouse gas emissions, and most of these emissions are CO_2 (1). Over the last few decades, an increased concentration of CO_2 in the earth's atmosphere has been observed. Carbon sequestration technology offers an approach to redirect CO_2 emissions into sinks (e.g., geologic formations, oceans, soils and vegetation) and potentially stabilize future atmospheric CO_2 levels. Coal seams are attractive CO_2 sequestration sinks, due to their abundance and proximity to electricity-generation facilities. The recovery of marketable coal bed methane (CBM) provides a value-added stream, potentially reducing the cost to sequester CO_2 gas. Much research is needed to evaluate this technology in terms of CO_2 storage capacity, sequestration stability, commercial feasibility and overall economics.

CONSOL, with support from the U.S. DOE, has embarked on a seven-year program to construct and operate a coal bed sequestration site composed of a series wells that originate at the surface and extend horizontally through two overlying coal seams. Once completed, all of the wells will be used initially to drain CBM from both the upper (mineable) and lower (unmineable) coal seams. After sufficient depletion of the reservoir, centrally located wells in the lower coal seam will be converted from CBM drainage wells to CO_2 injection ports. CO_2 will be measured and injected into the lower unmineable coal seam while CBM continues to drain from both seams. In addition to metering all injected CO_2 and recovered CBM, the program includes additional monitoring wells to further examine horizontal and vertical migration of CO_2.

CONSOL's BACKGROUND

CONSOL, headquartered in Pittsburgh, Pennsylvania, is a coal mining company with operations dating back to 1864. Currently, CONSOL has coal operations in five U.S. states (and Australia) and operates more longwall mining systems than any other U.S. coal producer. In addition, CONSOL is the largest exporter of coal in the U.S. In recent years, CONSOL has expanded its business to include the capture and sale of pipeline-quality CBM. CONSOL's gas operations are headquartered in Virginia (central Appalachia), but CBM operations have been recently expanding into Pennsylvania and West Virginia (northern Appalachia).

In Virginia, CBM is primarily recovered through hydraulically fractured vertical production wells. With this approach, a vertical borehole is drilled to the target coal seam(s) and gas production is stimulated by hydraulically fracturing (or fracing) the seam. Hydraulic fracing is a process in which high-pressure water or a water/nitrogen foam, is mixed with size-graded sand and pumped into the coal seam. At a critical pressure, the seam fractures and the water/sand rushes into the fracture formed in the seam. Upon completion, the water is recovered, but the sand remains to prop open the fracture. The openings created by the sand allow methane to flow through the coal seam to the vertical well. Whether the fracture, or frac, propagates within the coal seam or out of the coal seam is dependent on the surrounding geology. For example, in the Pocahontas No. 3 Seam, the compressive strength of the coal seam is about 3,000 psi.

The roof and coal shales surrounding the coal have a compressive strength of approximately 13,000 psi. The hydrofrac is, therefore, successfully contained in the coal and typically propagates up to and beyond 500 feet on either side of the well (refer to Figure 1).

Hydraulic fracing has proven to be a less effective approach for coals, such as those in the northern Appalachia, where the roof and floor strata around the coal seam are weak and cannot confine the fracture in the coal seam. The hydrofracs most often extend into the weaker geology of the roof (refer to Figure 2). Fracturing the roof, rather than the coal, greatly reduces the CBM recovery and CO_2 sequestration potential. CBM production and CO_2 sequestration primarily takes place in the coal seam, because the shale and fire clay above and below the coal seam do not contain methane gas and do not have an affinity for CO_2.

In the Pittsburgh seam, CONSOL employs guided horizontal drilling to degasify longwall panels and development entries in the coal seam prior to mining. In this technique, development entries surrounding longwall panels are created using continuous miners. From these entries, horizontal boreholes (up to 3,000 feet in length) are drilled to degasify the longwall panel and subsequent development entry. However, this technique does not allow maximum methane production, because mine timing requires that the boreholes be mined through within a few months of completion. As a result, upon mining the methane remaining in the coal is emitted to the atmosphere with the mine ventilation air. Furthermore, this technique has no direct application for CO_2 sequestration because it is practiced only in mineable seams.

CONSOL believes that drilling wells that originate at the surface and extend horizontally through the coal seam affords the greatest potential for optimizing both CBM recovery and CO_2 sequestration in northern Appalachia. Horizontal drilling does not require strong roof and floor strata to be effective and can exploit a large areal extent of the coal reserve from a single surface location. Furthermore, this approach allows recovery of the CBM resource from both the mineable and unmineable coal seam. When applied to carbon sequestration, horizontal wells offer dual greenhouse-gas-reduction benefits: 1) avoid methane emissions from the mineable seam; and 2) sequester CO_2 in the umineable seam.

PROGRAM OBJECTIVES

CONSOL has proceeded with the field construction phase of a seven-year program designed to evaluate both CBM recovery and CO_2 adsorption capacity of an unmineable coal seam. The program objectives are as follows:

- Demonstrate horizontal drilling in underground coal seams
- Define effective CO_2 injection methods and procedures
- Evaluate the CO_2 adsorption capacity of coal beds
- Measure the effects of CO_2 injection on CBM recovery
- Monitor the concentration of CO_2 in the recovered CBM over an extended period of time
- Assess the overall effectiveness and economics of CO_2 sequestration with this approach

PROJECT DESCRIPTION

The field layout for CONSOL's project mimics a traditional five-spot well design, which is commonly used in the oil and gas industry. However, vertical wells are replaced with horizontal wells. The design includes multiple horizontal wells into the subsurface from three surface locations (refer to Figure 3). From each corner well site (Well Site A and C), directional drilling will be used to complete two horizontal wells (extending up to 3,000 feet) at 90 degrees of separation in the upper/mineable coal seam. Similarly, two horizontal wells will be completed in the lower/unmineable coal seam. Upon completion, these eight horizontal wells will form the sides of a square in each of the two overlying coal seams. At the center well site (Well Site B), four horizontal wells (extending up to 1,000 feet) at 90 degrees of separation will be completed in the lower/unmineable seam. These four centrally located wells will further exploit the lower seam reservoir and ultimately be used for CO_2 injection. In total, twelve horizontal wells will be drilled for the project, four in the upper/mineable seam and eight in the lower/unmineable seam. The illustration shown in Figure 4 depicts a conceptual view of the project.

Following drilling, gathering pipelines will be constructed to collect the CBM recovered from the three project well sites to a central location. From this location, the recovered CBM will be treated and compressed as necessary to deliver the captured CBM to a receiving pipeline. Initially, CBM will be recovered from all three well sites (from both the upper/mineable seam and the lower/unmineable seam). CBM recovery will continue for a sufficient period of time to deplete the reservoir prior to CO_2 injection. In time, a source of CO_2 will be established near the center well site (Well Site B) and the four horizontal wells at that site will be converted to injection ports. Carbon dioxide gas will then be compressed, metered and injected into the lower/unmineable coal seam, while CBM recovery continues at the corner wells (Well Sites A and C). CO_2 injection is expected to continue in this manner for approximately two years.

The concentration of CO_2 present in the CBM recovered from the project wells will be measured and recorded throughout the project; i.e. before, during, and after CO_2 injection. As a result, CBM recovered from the upper/mineable seam will serve to monitor any vertical migration of CO_2. Similarly, CBM recovered from the corner wells of the lower/unmineable seam will serve to monitor horizontal migration or breakthrough of CO_2. The project includes additional wells to further monitor horizontal and vertical migration of CO_2.

An outline of project tasks is shown in Figure 5.

PROGRESS TO DATE

Site Selection

In 2001, CONSOL completed seven exploratory core holes in northern West Virginia. The geologic logs from those core holes were obtained and utilized to evaluate potential locations for the project. Geologic data from the southern cores indicated very thin or non-existent lower coal seams in that area. The northern cores taken from Marshall County, West Virginia, however, were much more promising in terms of lower coal seam thickness and continuity. A location near one of the core holes was judged most favorable for the project in terms of thickness of the coal seams, accessibility, and topography. Further evaluation of the logs indicated that the thickness of the Upper Freeport seam remained more uniform throughout the area relative to the other lower/unmineable coal seams.

For these reasons, a location in Marshall County, West Virginia, was selected for the project. Furthermore, the Upper Freeport coal seam was selected as the lower/unmineable seam for the project. The Pittsburgh seam is the upper/mineable seam for the project. Desorption tests on the core samples taken from the selected site were completed in March 2002 and those results are shown below in Table 1.

Table 1. Evaluation of Core Samples from the Selected Site

Coal Seam	Seam Thickness (Feet)	Depth to Top of Seam (Feet)	Gas Content (Std. Ft^3/Ton)
Pittsburgh	6.72	669.4	136
Upper Freeport	4.25	1260.9	182

Gas contents are listed on a dry, ash free basis and include desorbed, residual and lost gases.

A map showing the general location of the project site is shown in Figure 6. A preliminary drilling plan for the project is drawn to scale and shown projected over a topographical map in Figure 7.

Permitting

Prior to commencing any permitting work, a substantial amount of land work was required for this project. All land work was completed by CNX Land Resources Inc. (CNX Land), a subsidiary of CONSOL. CNX Land identified all landowners and secured all surface and subsurface property rights necessary for the three project well locations. At one location, it was necessary to file a partition suit in order to secure subsurface coal rights that had been partitioned through multiple heirships. CONSOL was awarded the outstanding coal rights at a court ruling in September 2002. In addition, CNX Land completed land use agreements with three separate landowners. These agreements enabled CONSOL to proceed with the surface construction activities of the project.

A contractor was hired to conduct necessary surveys and prepare permit applications for all the project wells in Marshall County. Well permits for the north corner wells of the project (Well Site A) were submitted in August 2002 and approved by the West Virginia Department of Environmental Protection in November 2002. Similarly, well permits for the south corner were approved in January 2003. The drilling plan for the center wells was amended; approval of the well permits for that location is anticipated in May 2003.

Environmental Assessment

In order to comply with the National Environmental Policy Act of 1969 (NEPA), CONSOL was required to supply to DOE an environmental assessment describing the project and its potential environmental impacts on the environment. Groundbreaking activities for the project were contingent upon satisfying these NEPA requirements. A 44-page report was prepared and submitted to NETL in February 2002. At NETL's request, CONSOL supplied additional quantitative information about the project in May 2002. In October 2002, following numerous interactions with NETL and state and federal agencies, CONSOL was granted NEPA approval limited to the north well site of the project. An archeological survey, required by the West Virginia Division of Culture and History, was completed in November 2002. CONSOL was granted final NEPA approval for the project (for all well sites) in March 2003.

Site Preparation

With NEPA approval and well permits secured, site preparation work commenced at the north corner well site of the project in November 2002. Excavation contractors constructed an access road (approximately one mile in length) from the existing township road to the designated well site. Additional construction, including timbering, earthwork, and hauling stone, was completed at the well site prior to employing the drilling contractors. All site preparation activity at the north well site was completed in December 2002. Likewise, site preparation work at the south corner well site began in March 2003 and was completed in April 2003.

Drilling

Contractors began drilling at the north well site in December 2002. The drill plan for this location included four horizontal wells, two in the Pittsburgh seam and two in the Upper Freeport seam. After completing the vertical component of the first well, a vertical borehole extending below the Upper Freeport seam was drilled. This borehole was used to complete a natural gamma log and establish a datum for this location. The results of the log revealed the Pittsburgh seam to be 1,125 feet deep and 7.5 feet thick. Similarly, the Upper Freeport seam was 1,716 feet deep and 5.0 feet thick.

The two horizontal wells (at 90 degrees of separation) in the Pittsburgh seam were completed to 3,000 feet as originally planned. While progressing on the first horizontal well in the Upper Freeport seam, the drilling contractors determined that the seam thickness had thinned to less than eighteen inches. Consequently, that well was completed with 2,200 feet of horizontal extension. The drilling contractors experienced other challenges on the fourth well that prevented the completion of that well. As a result, CONSOL elected to halt drilling operations in February and return to this location later in 2003.

Drilling at the south corner location is projected to begin in May 2003.

FUTURE WORK

CONSOL expects to complete the drilling for all the project wells by October 2003. Construction of a gathering system should be complete in 2004. CBM recovery is projected to take place from 2004 through 2008. Likewise, monitoring would take place in 2004 through 2008. CO_2 injection is projected to begin in 2005 and continue through most of 2007.

REFERENCES

(1) U.S. Environmental Protection Agency, 2000 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1998, EPA 236-R-00-001, April 2000.

Figure 1. Successful Hydrofrac

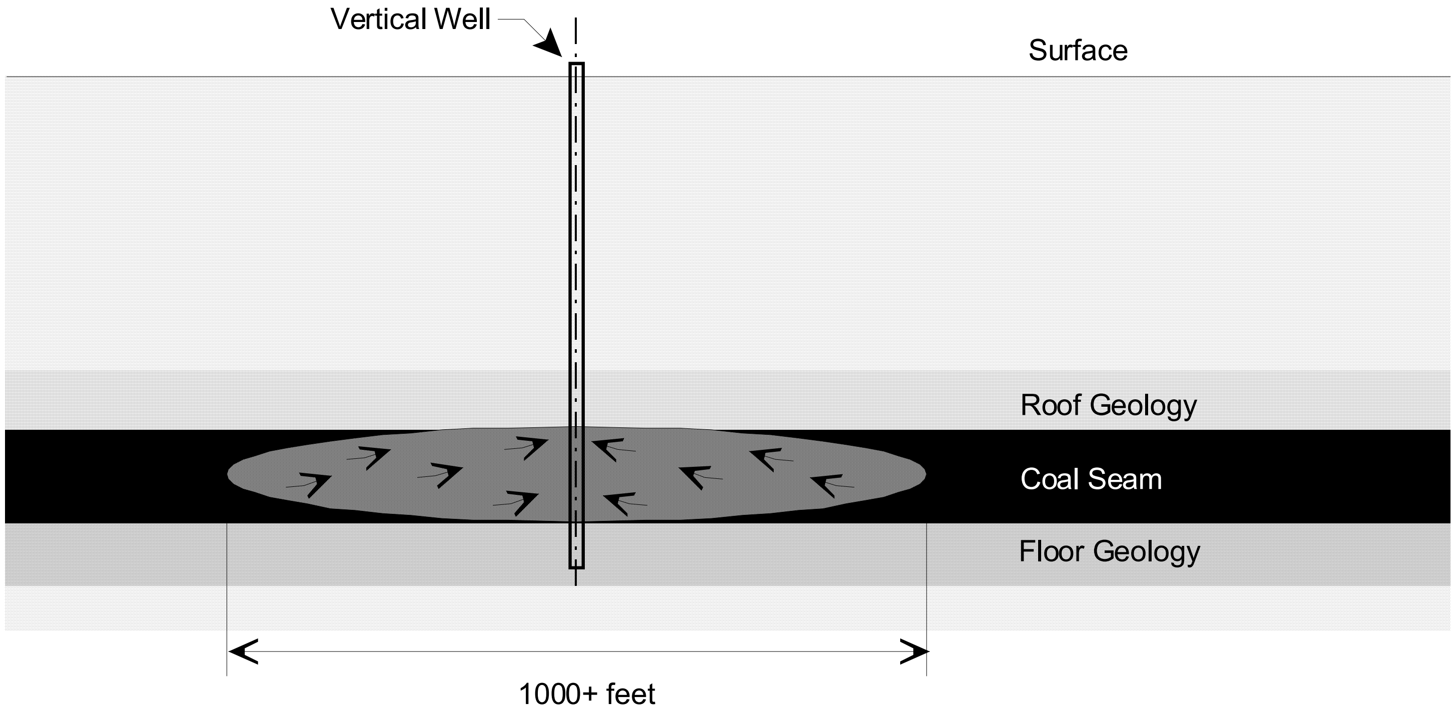

Figure 2. Unsuccessful Hydrofrac

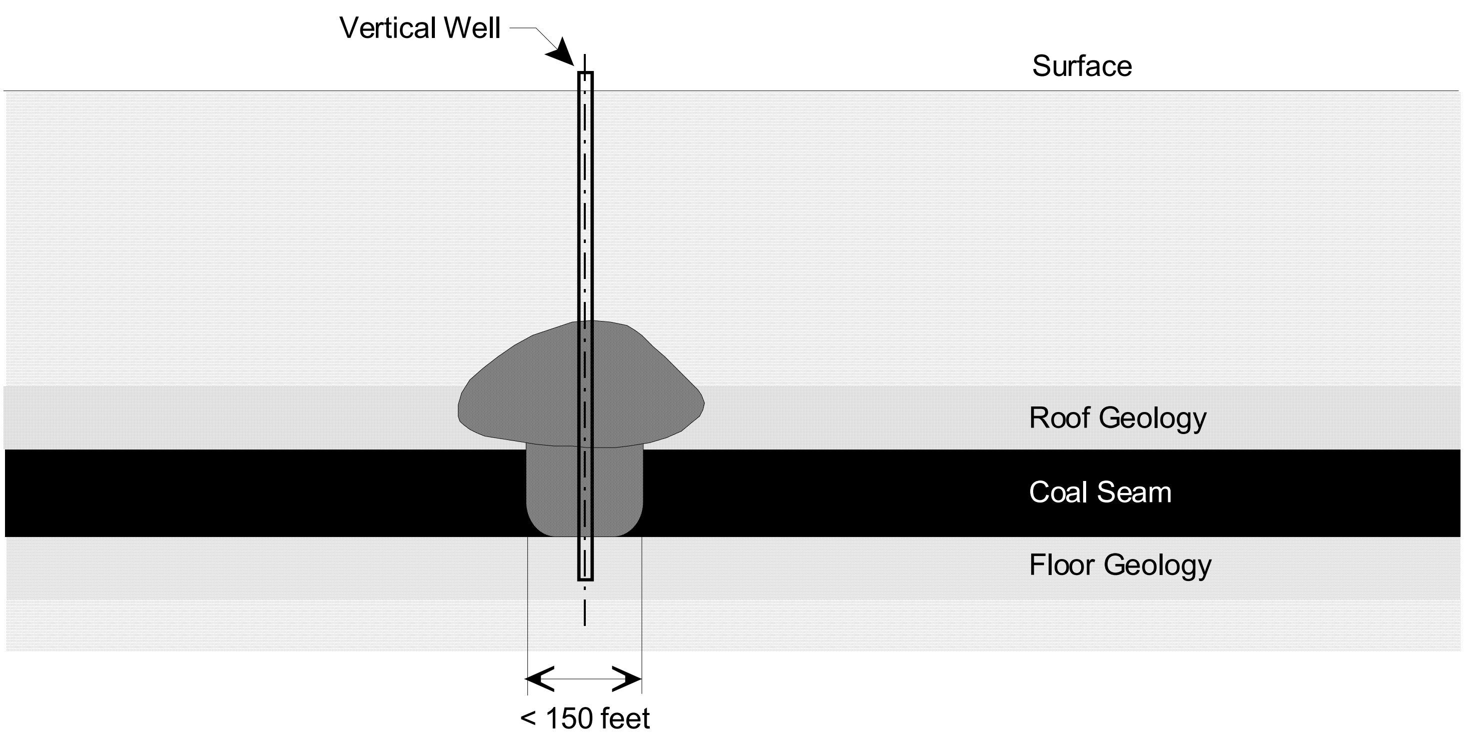

Figure 3. Plan View

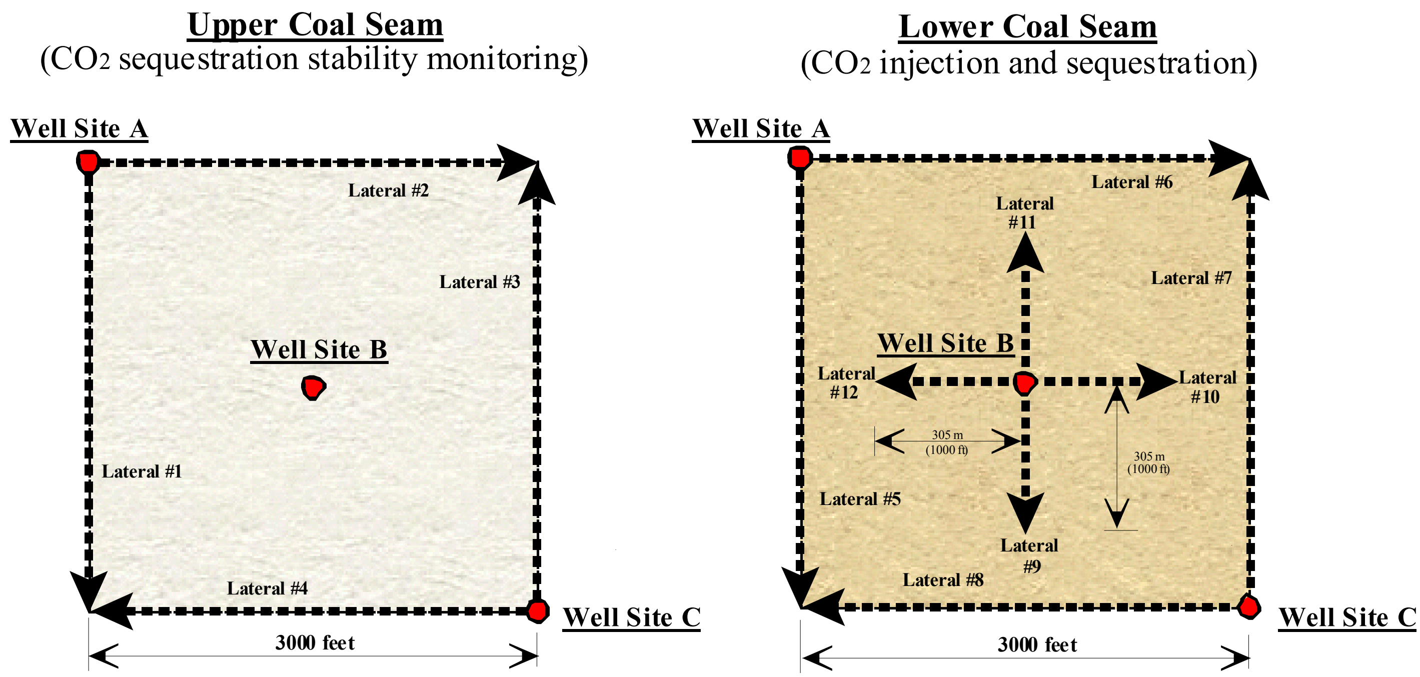

Figure 4. Conceptual Illustration of Project

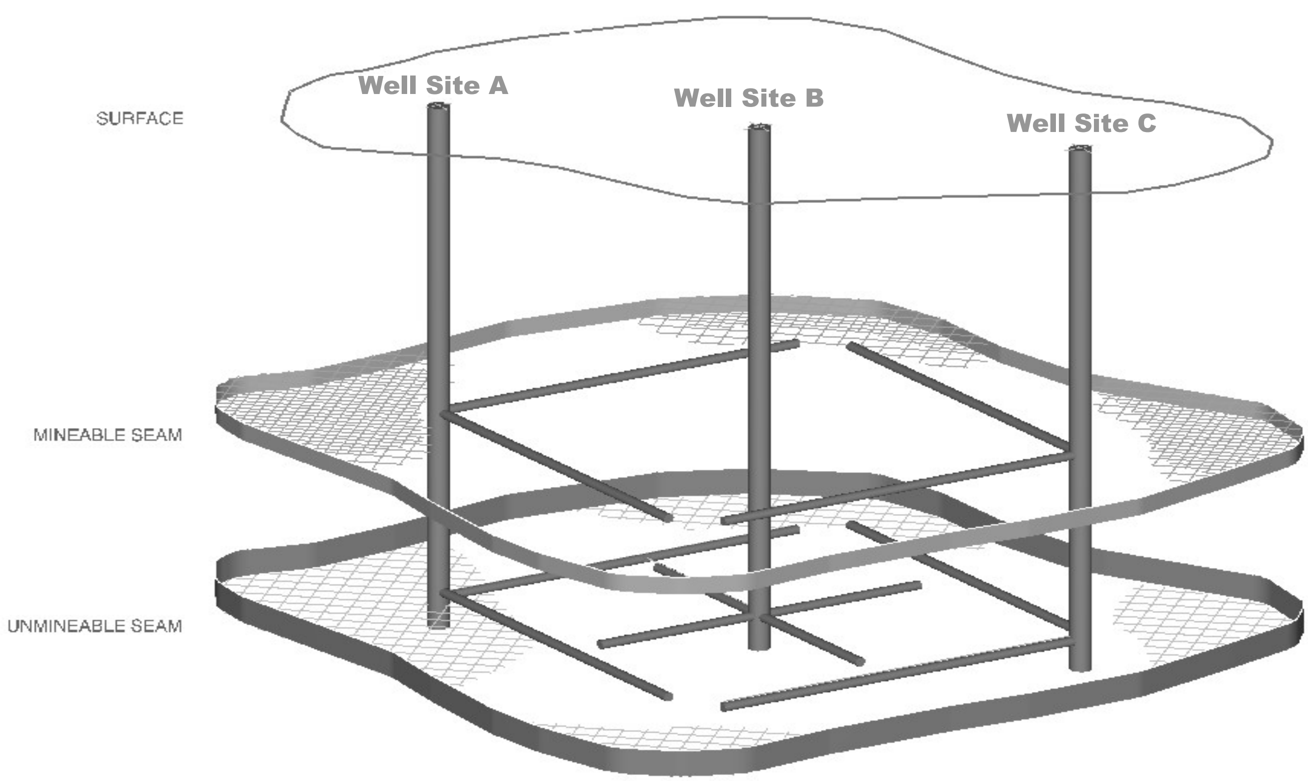

Figure 5. Project Tasks

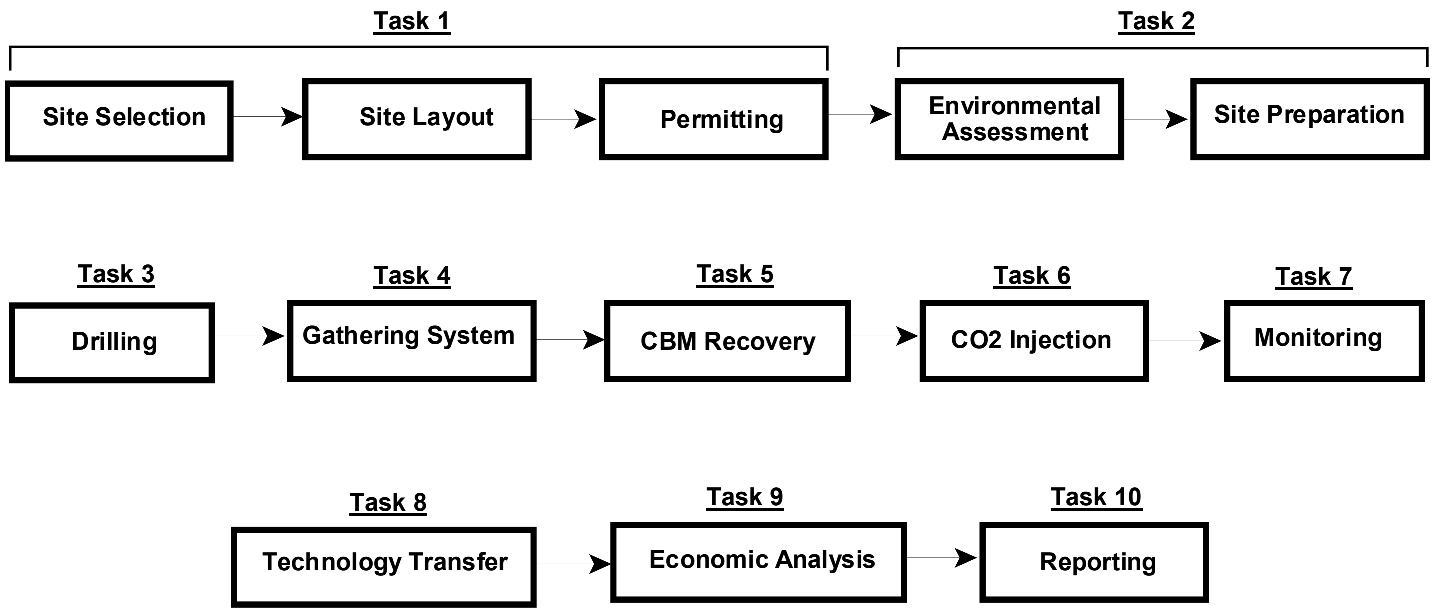

Figure 6. General Location of Project Site in Marshall County, West Virginia

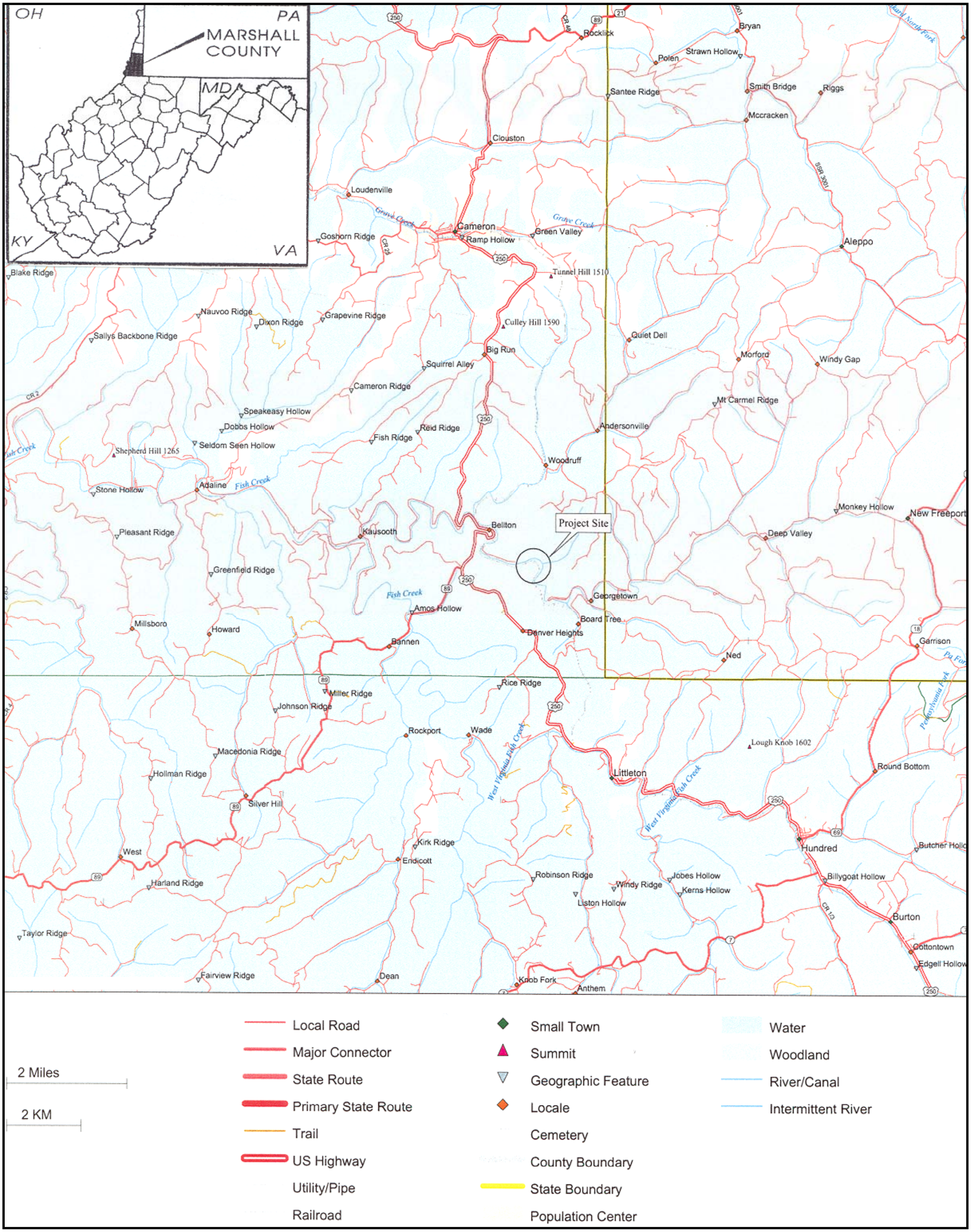

Figure 7. Specific Location of Project